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Regular Articles

Multi-channel fiber optic dew and humidity sensor

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ABSTRACT

In this article, we introduce a multi-channel fiber optic dew and humidity sensor which works using a novel method based on relation between surface plasmon resonance (SPR) and water vapor condensation. The proposed sensor can instantly detect moisture or dew formation through its fiber optic channels, separately situated in different places. It enables to simultaneously measure the ambient Relative Humidity (RH) and dew point temperature of several environments with accuracy of 5%.

1. Introduction

Moisture monitoring is essential to prevent potentially catastrophic consequences and poor end-product quality in various industries. Hence, there is extensive demands for high-efficiency environmental sensors in market, especially for humidity controlling for microclimate systems that are individually distributed in combustible or hazardous industrial locations, clinics, clean rooms, museums, combustible or hazardous places, homes, and in nature [1,2]. In fact, current electrical based humidity sensors in market have difficulties to be used in environments with stringent limitations on physical space, and also chemical conditions, due to restrictions of their probes in term of size and structure. Fiber optic based technologies offer features such as ultrafast, lightweight, non-intrusive, flexible and remote sensing capabilities. Hence numerous investigations have been conducted on the use of optical and fiber optic based technologies for humidity sensing applications [3–7]. In general, these sensors utilize direct spectroscopic [8], evanescent wave [9], in-fiber grating [10,11], interferometric, or hybrid [12–15] methods to measure humidity.

It is often argued that optical based humidity sensors can be substituted with the electrical based sensors in markets because of their privileges. But in spite of the all efforts done over the past quarter century, this expectation has been not realized yet. One of main obstacles for developing and substituting of the optical based sensors with their electrical counterparts is that their price are not cost-effective. Most of previously introduced optical technologies, e.g. Fiber Bragg Grating (FBG) based sensors, use relatively expensive optical components such as probes, light sources and detectors. Hence it seems the electronic sensors is likely to remain the technology of choice for the vast majority of sensing applications in the market, unless the cost of the optical based sensors is essentially reduced. To reduce the price, it requires to design optical fiber sensors that use cost-effective components including light source, transducer, and detector.

In this paper we propose a multi-channel optical dew & humidity sensor (MODHS), as an efficient and cost-effective solution. A developed MODHS enables to simultaneously monitor dew point and humidity of a suite of microclimate systems in hard-to-access industrial locations, museums, archive rooms, libraries, laboratories, and etc. Thanks to innovative design used in our sensor in both technical and conceptual aspects, the proposed sensor has some remarkable advantages and features. It employs simple photoconductive cells or photodiodes for detection, instead to use expensive spectrometers. Also the sensor employs a simple LED, as the light source, to simultaneously supply measuring light of several fiber optic channels. In the conceptual aspect, the MODHS employs a novel sensing method, based on surface plasmon resonance (SPR) and water vapor condensation [16,17], thereby, the sensor is exempted to have any moisture absorbent layer, in contrast with other humidity sensors.

The remainder of this paper is organized as follows. Section 2 begins with a demonstration about the proposed system embodiment, including general layout and its components. In Section 3, we discuss how ambient Relative Humidity is measured in our MODHS via two techniques, the tradition and our proposed method. Finally, the conclusion comes in Section 4 of this article.

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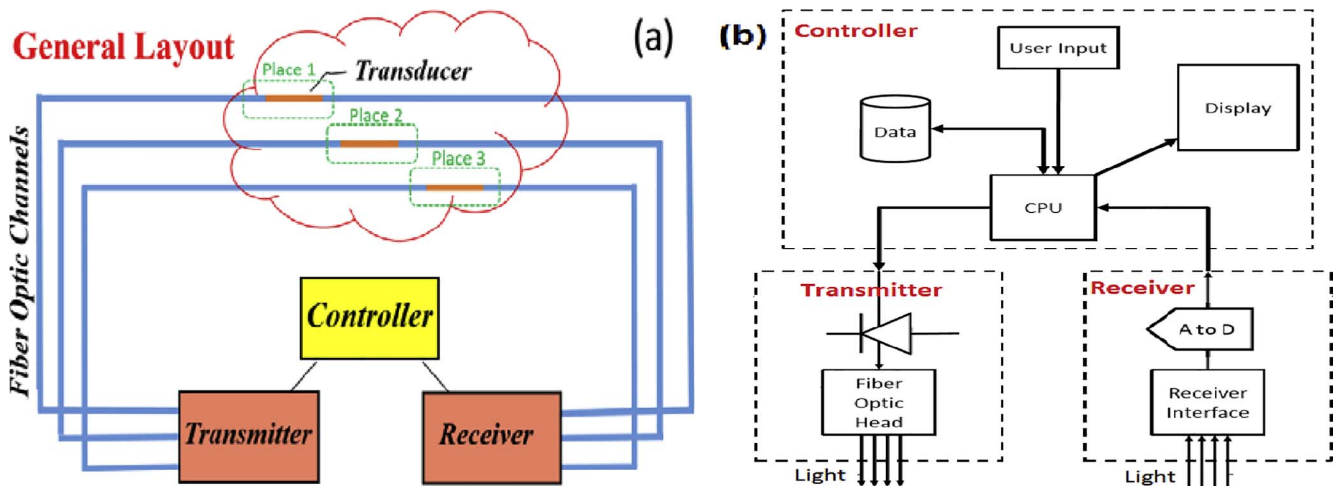

Fig. 1. (a) A general layout of multi-channel optical dew and humidity sensing (MODHS) system. (b) A schematic diagram of the MODHS including: transmitter, receiver and controller.

2. Instrument description

2.1. General layout

In this section we describe our proposed MODHS system and Fig. 1a shows its general layout. The system comprising light transmitter, controller, receiver, and a plurality of optical fibers each comprising a first end fed the measuring light, and a transducer positioned along a length thereof.

Each optical fiber is connected to a light transmitter at one end and a receiver at another end. The transmitter and receiver are connected to and under the control of a controller. The transducers are situated inside a wet area whose dew point temperature and humidity level are to be measured. Referring to Fig. 1b, the controller comprises a microcontroller (CPU), a data store, a user input and a display. The receiver comprises a Fiber Channel Angled Physical Contact (FC/APC) mating sleeve, a photoconductive cell, an amplifier 40X-Gain, and an analog to digital (A to D) converter, illustratively a 24-bit analog to digital converter. A user would use the user input to activate the light source via the CPU.

The measuring light would then be modified via the transducers before returning via the plurality of optical fibers to the receiver by a FC/APC type connector. The optical power of the received measuring light, illustratively measured in microwatts, would then be converted into an electrical signal, illustratively DC voltage, using the photoconductive cell, the electrical signal then amplified by the amplifier. The amplified electrical signal is then converted into a digital signal using the A to D converter, the newly converted digital signal sent back to the CPU for analysis, the results of which would appear on the display and be stored in the data store for further comparison and analysis purposes. As described, the system includes of optical and electronic modules. We intent to only investigate its optical sections, such as transducer and the transmitter, in the following sections.

2.2. Light transmitter

The transmitter comprises a light source, illustratively a red LED, and a fiber optic head connected to the plurality of optical fibers, as schematically shown in Fig. 2a. The light source is a simple low-cost super bright LED, in red color, and it is power supplied by DC-voltage of 3 V. The emitted light from the LED should maximally be lunched into the fiber optic head resulting a better signal-to-noise ratio. Hence we polished the LED to form a smooth flat surface on its tip to make a perfect physical contact and also adjust the optimum distance between the LED and the fiber optic head to get a maximum light coupling.

2.3. Moisture transducer and sensing mechanism

The transducer is a SPR based fiber optic sensor comprising a portion of fiber optic wherein the fiber is side-polished, depicted in Fig. 3a, and coated by a thin gold layer. Surface Plasmons are appeared on the gold surface upon phase-matching condition is occured, i.e. equality of propagation constants between SP waves and the core guided light in the fiber. This condition can be realized whenever a small amount of moisture forms on the surface of the sensor due to water vapor condensation as soon as the sensor temperature reaches to the ambient dewpoint ($T_s = T_{dew}$). Since surface plasmons are lossy waves, then a measurable decrease in transmission light intensity is observed because of SPR effect. Using this concept, we developed a fiber optic humidity sensor based on relation of the SPR and vapor condensation phenomena. The transducer modifies an intensity of the measuring light dependent on an ambient humidity by detecting changes in thickness of a layer of water on the polished portion.

In our case, the transducer uses a standard multimode fiber (62/125 μm), where up to a 15 mm length the fiber is side-polished, with a remaining cladding thickness of 1–2 μm. A 45-nm-thick layer of gold is coated on the polished area. Fig. 3b presents a top view of the sensing area in our sensor, where the surface is wetted due to condensation of water molecules, contained in the adjacent air. As shown, the size of water droplets are in the range from a few hundred nanometers to a few microns, implying that the thickness of the water layer on the surface of the sensing area should be in submicron scale. Hence, our SPR-based fiber optic sensor enables the immediate detection of moisture formation and its thickness variations.

3. Results and discussion

3.1. Test of multi-channel optical dew and humidity sensor (MODHS) in traditional regime

Although our fabricated optical head can support seven transducers in seven channels, but here we present the measurement results only for three channels because of equipment considerations in our measurement system. The current platform can be developed to a prototype system with more than 50 channels. Fig. 4a shows real-time measurement of optical transmission of three transducers in three channels No. 1, 2, and 3, situated in three different chambers. The chambers have transparent acrylic walls, and are also equipped by air conditioning and measurement equipments. The level of the ambient humidity inside each chamber is changed by flowing moist air using ultrasonic humidifiers and then after exhausting the humidified air, in atmospheric pressure and room temperature condition.